DS1 Tone Detection Experiments:
History and Current Status

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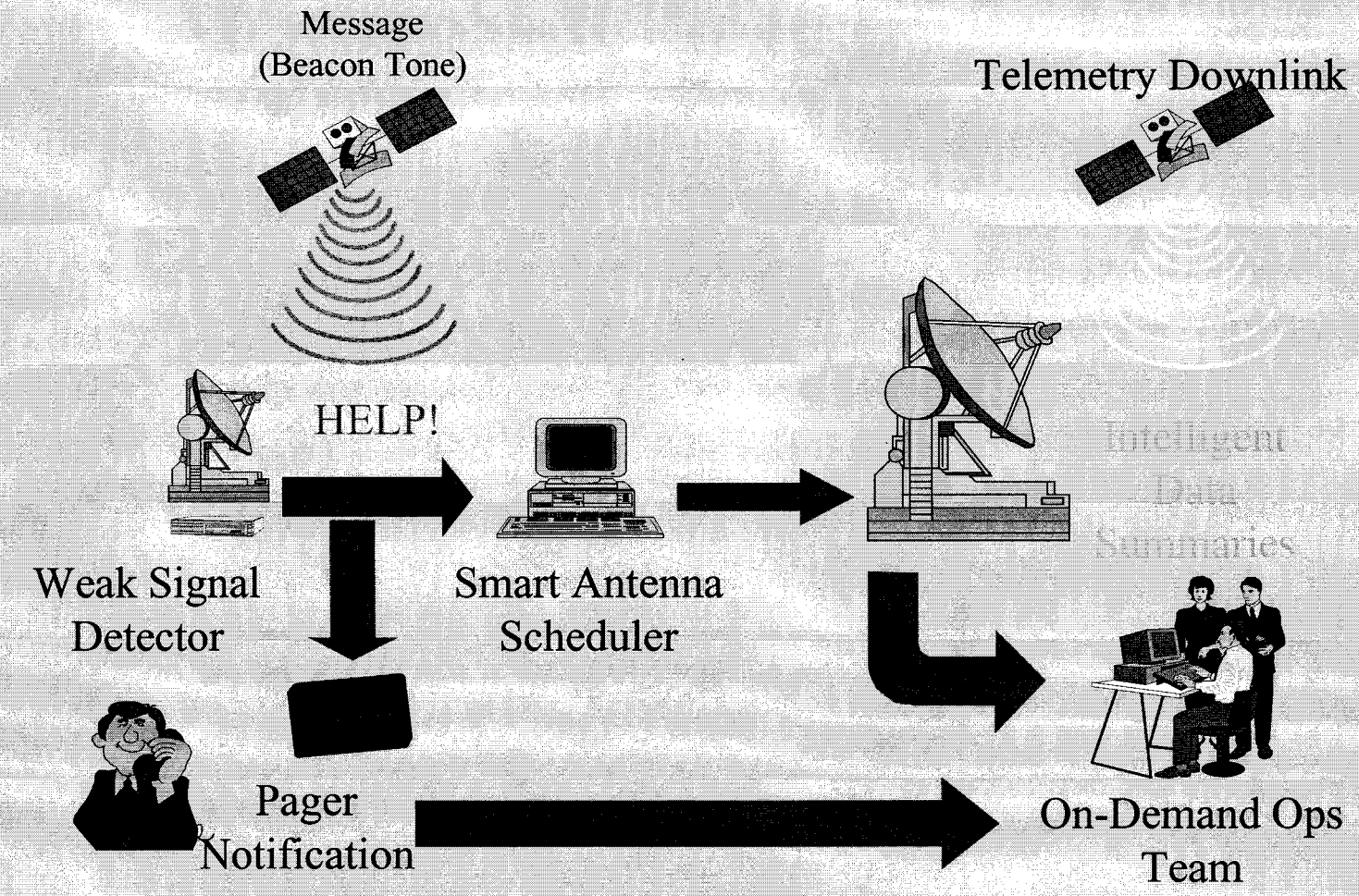
Introduction

- The DS1 Beacon Monitor Operations Experiment (BMOX) was to demonstrate a new approach in mission operations which can lower mission operations costs
- Operations Concept
  - The s/c analyzes on-board engineering data, determines its health state and the need for ground contact, maps health states into a limited set of urgency-based short messages, and transmits this message to the ground
  - The ground detects the message, and responds accordingly
- BMOX Experiments
  - Data Summarization, Tone (message) Selector, Ground Visualization
  - Tone detection and message delivery
    - Characterize operational performance
    - Demonstrate automated signal detection and message delivery operations

Operational Concept



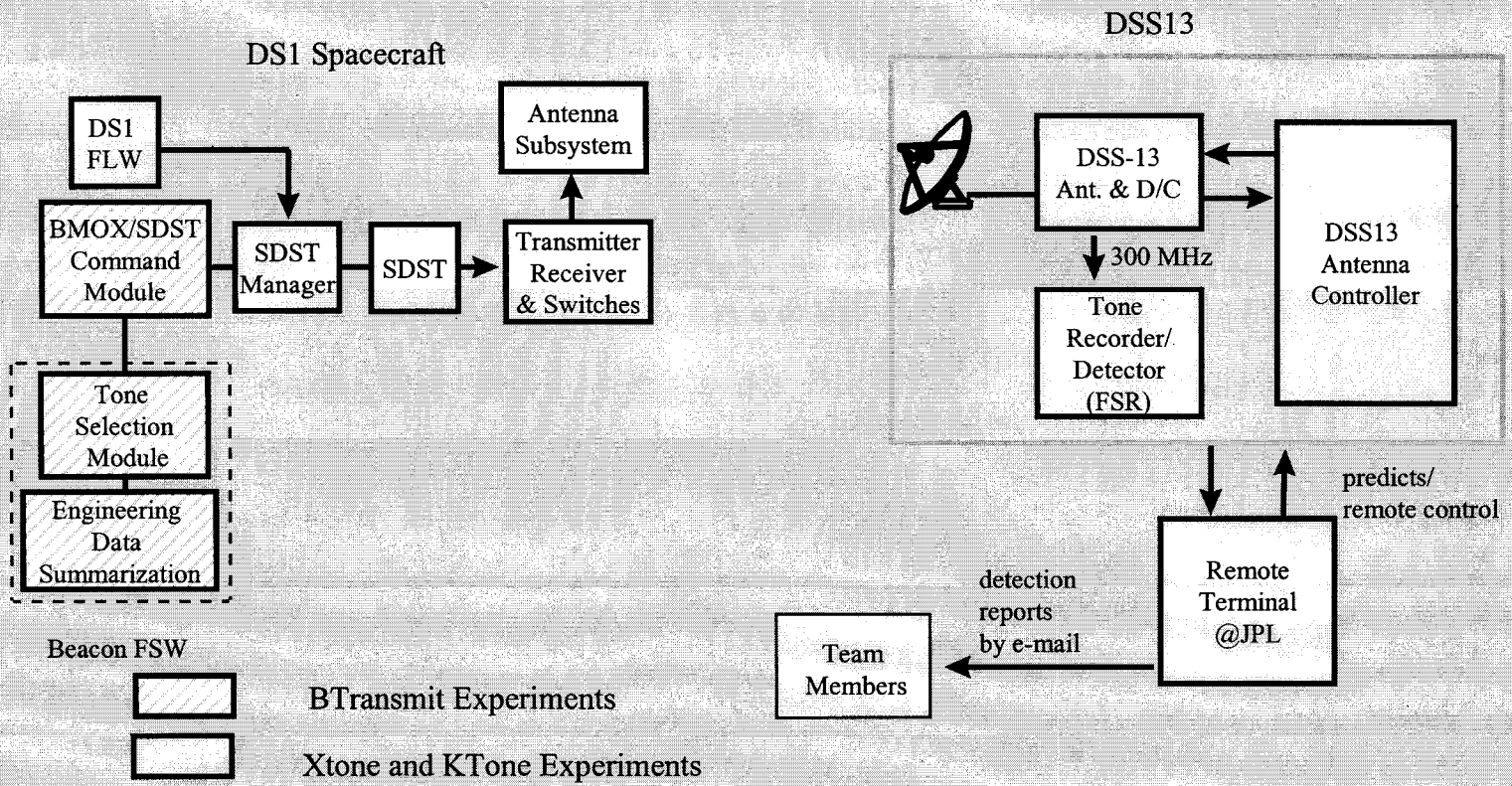
DS1 Tone Signal Structure

- Four messages: Nominal, Interesting, Important, and Urgent
- Each message is represented by a pair of tones with a unique spacing.
- Each tone pair is generated by modulating the RF carrier with a squarewave subcarrier using 90 deg. modulation angle. The subcarrier frequencies are: 35,30,25 and 20 KHz
- Factors determining tone spacing: frequency stability, residual Doppler and Doppler rate, etc.

Possible Message Definitions

Tones	Definition
Nominal	Spacecraft is nominal, all functions are performing as expected. No need to downlink.
Interesting	Establish communication with the ground when convenient to download engineering summary or telemetry.
Important	The spacecraft needs servicing. Communication with the ground needs to be achieved within a certain time.
Urgent	Spacecraft emergency. A critical component of the spacecraft has failed.
"No Tone "	Beacon mode is not operating. Spacecraft telecom or ground equipment is not working properly.

DS1 Tone Detection and Message Delivery System



Sample Tone Detection Report

Date: Thu, 18 Mar 1999 15:58:23 -0800 (PST)
From: Gabor Lanyi <gel@psdg.jpl.nasa.gov>
Identifier: ds1.dss13.990318-154828.077-224731.003

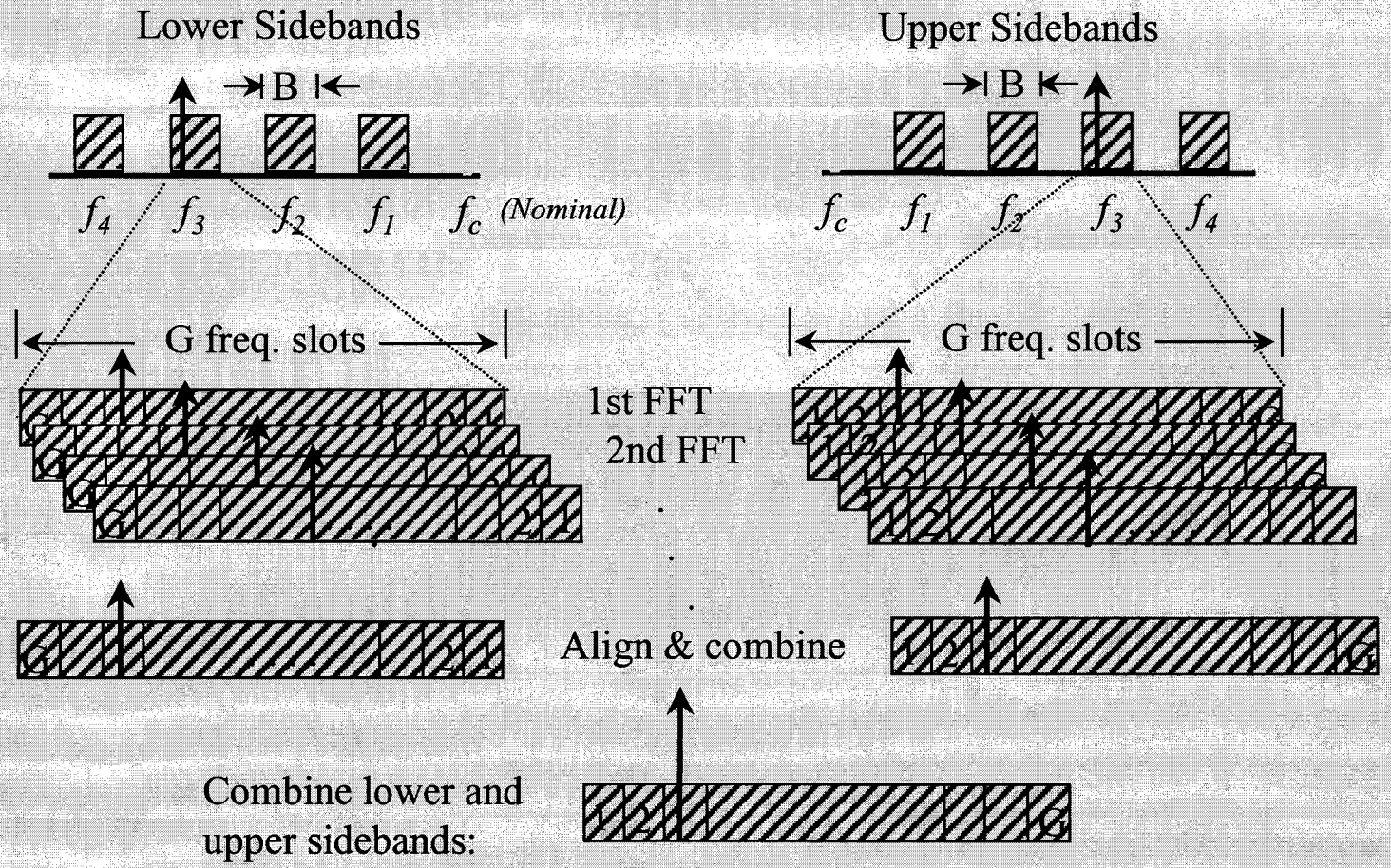
Detected_Parameters

Status:	signal_detected
Signal_Frequency_Detected(kHz):	19.99453
Carrier_Frequency_Estimated(GHz):	8.421804271
Frequency_Rate_Detected(Hz/s):	-0.06
Power_Signal_to_Noise_Ratio_Estimated(dB-Hz):	5.0
Missed_Detection_Probability_Observed<:	1.0e-10
False_Detection_Probability_Observed:	5.4e-06

Input_Parameters

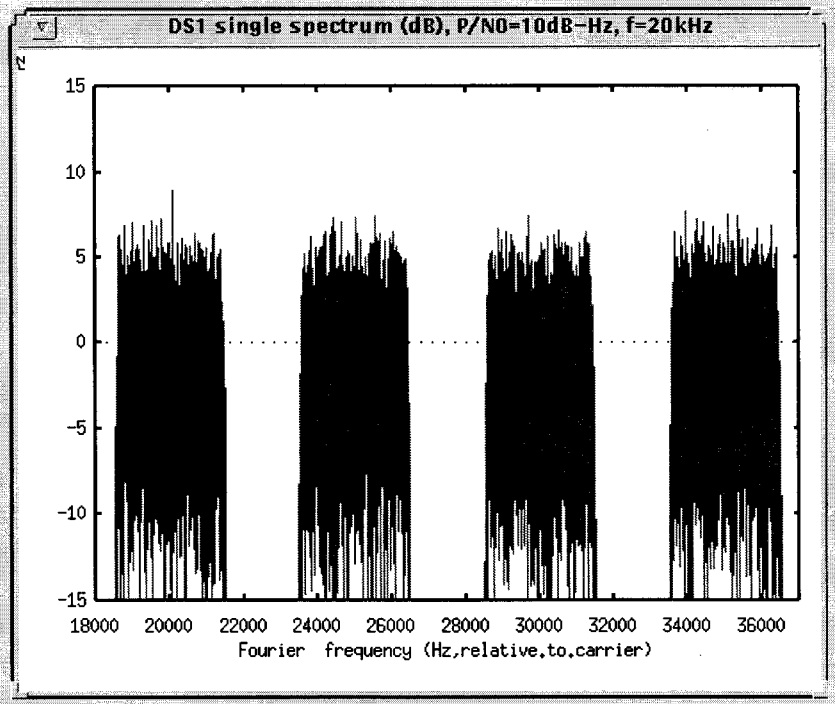
Carrier_Frequency_Predicted(GHz):	8.421784276
Probability_of_False_Detection_Criterion:	1.0e-02
Threshold_from_Prob_Fals_Det(dB-Hz):	3.6
Power_Signal_to_Noise_Ratio_Predicted(dB-Hz):	10.0
Missed_Detection_Probability_Predicted:	1.0e-02
Start_Time:	99/077/23/10/00
No_of_Fourier_Transforms:	15
Duration_of_Fourier_Transform(s):	1.00

Detection Algorithm

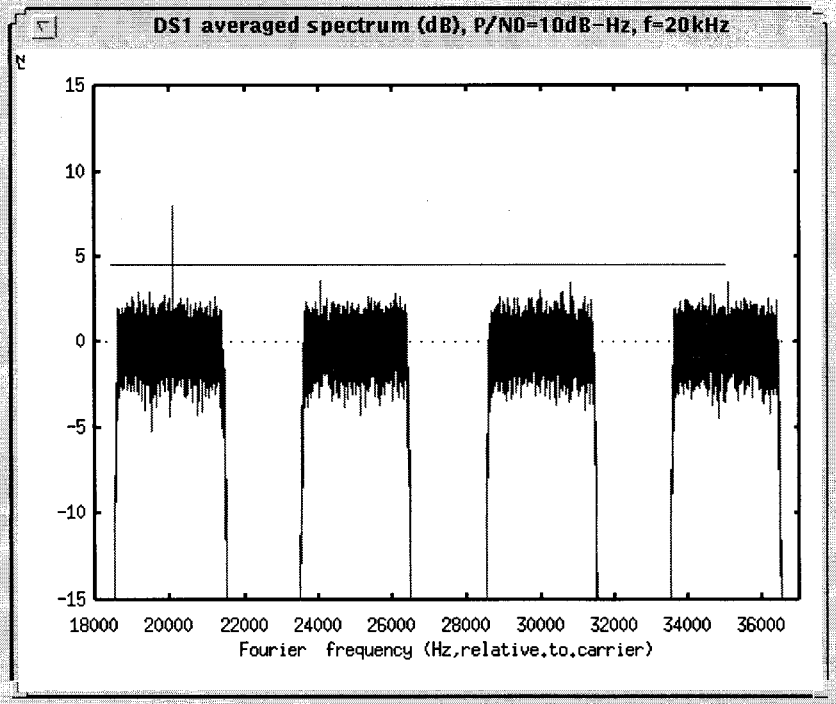


Repeat for other tone pairs, select max, & compare with threshold to make detection decision.

Aligning and Combining Improves Signal Detectibility



1-sec



10- sec

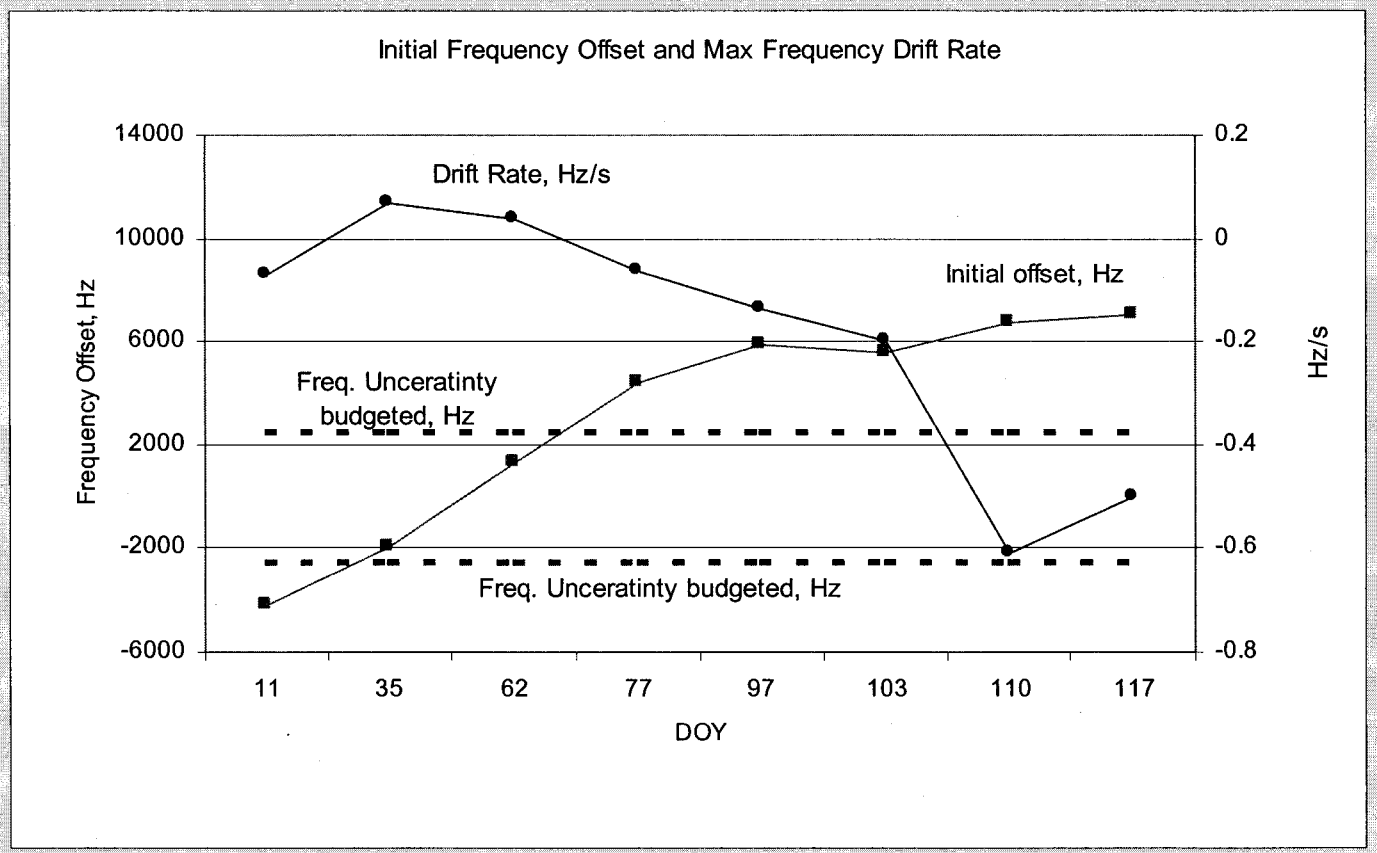
Summary of Experiments:
X-Tone

- Conducted 7 X-Tone experiments using both HGA and LGA
- Objectives
  - Check out the functionality of the tone detection and message delivery system, characterize operational performance, obtain parameter limits
- Methodology
  - Tones were pre-selected (unknown to the BMOX team), sequenced, and uploaded to the spacecraft
  - Post-pass comparisons against uploaded sequences or s/c TLM were made to validate detection results
- Results
  - 5 successful passes and 2 partial successful passes
    - DSS-13 antenna computers down; strong wind halted antenna
    - Large frequency offset
- Lowest detection SNR ~5 dB-Hz based on preliminary analysis

Summary of Experiments:
Ka-Tone and Btransmit

- Conducted 1 Ka-Tone experiment
  - Objective: to demonstrate tone signaling and detection at Ka-band
  - Results: Ka-tones were successfully detected
- Conducted 3 Btransmit Experiments
  - Objective: to demonstrate end-to-end operations from tone selection by on-board software, to signal detection and message delivery on the ground
  - Methodology
    - Tones were selected by on-board software using engineering summary data
    - Post-pass comparison with s/c telemetry was made to validate experiment results
  - Results: 3 successful selections and detections

Frequency Offset and Max. Frequency Drift Rates



Conclusions and Future Plan

- Lessons learned
  - Initial frequency uncertainty is larger than anticipated
  - Ways to reduce frequency offset is needed
- Future plan
  - Complete data analysis to characterize operational performance
  - Infuse technology to DS1 mission ops
    - Automate signal detection and message delivery operations
  - Improve very weak signal search algorithm
  - Use auxiliary oscillator temperature data to improve frequency predicts
- Possible future applications
  - Pluto-Kuiper Express
  - Europa Orbiter
  - Mars Sample Return missions (for the Mars Ascend Vehicle)

DS1 Tone Detection Experiments: History and Current Status

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Summary:

A new approach to mission operations, sometimes referred to as "Beacon Monitor" or "Beacon Mode", is being evaluated on NASA's New Millennium Program Deep Space One (DS1). In this approach, the spacecraft determines its health status and the need for ground contact. Subsequently, it maps the results into a few, short messages and transmits them to the ground. The messages are then detected and decoded by a receiving station. This approach has the potential of reducing deep space mission operations cost and decreasing the loading on NASA's Deep Space Network antennas. Major components of this technology include AI-based (artificial intelligence) onboard software, a messaging system, a ground response system, and a ground visualization system. The onboard software is used to analyze the housekeeping engineering data and to generate telemetry summaries, which will be prioritized and downloaded to the ground. The messaging system transmits, detects, decodes, and delivers the messages. The ground response system facilitates appropriate and timely responses to spacecraft messages. The ground visualization system is used to analyze telemetry summaries in order to gain insight into spacecraft states. Most of the component technologies have been validated on DS1.

The implementation of the messaging system and the signaling scheme used for the DS1 experiments will be presented. Various signaling schemes have been proposed to support this mission operations approach. The signaling scheme being evaluated on DS1 uses 4 pair of tones, each representing a unique message. The signaling scheme and theoretical performance will be reviewed. The results of various tone experiments performed on DS1 and lessons learned will be described. We will also discuss the potential future use of this technology.

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